XXVI. *An account of some experiments relative to the passage of radiant heat through glass screens. By the Rev.* Baden Powell, *M. A. F. R. S. of Oriel College, Oxford. Communicated March* 9, 1826.

Read June 1, 1826.

(1) In a former Paper, communicated to the Royal Society, and which has been honoured with a place in the Philosophical Transactions for 1825, I attempted an investigation of the distinctive characters of two species of heating effect, in which particular reference was made to the action of transparent screens. In the present communication, my object is to examine a further point belonging to that part of the subject; and to which, as well as the former enquiry, I have been led, from considering the results obtained by M. De La Roche. The investigation given in my former paper proceeded upon the assumption, that simple radiant heat is incapable of permeating glass by direct transmission when the source is below luminosity: and the conclusion deduced from my experiments went to show, that that portion of the heat which is intercepted above luminosity, is simple heat, unaltered except in intensity, whilst that which is transmitted is of a different kind.

That this assumption, at least under all ordinary circumstances, is warranted by most decisive experiments, I conceive sufficiently certain. It appears to me, however, that

in reference to its strict universality, some further enquiry is necessary. The general inference respecting transmission, deduced from DE LA ROCHE'S experiments, has, I conceive, been satisfactorily explained by mine; but there is one of his conclusions to which my principle does not apply (except in a particular case), and which might seem to afford considerable ground for the idea of an actual radiation through glass, under particular circumstances.

(2.) That distinguished experimenter found, that if radiant heat be intercepted by two transparent screens, the *additional* diminution of effect occasioned by the *second is proportionally much less* than that produced by the *first*; and the same conclusion is extended to any number of screens. This was explained by the supposition, that the heat in its passage through the first glass undergoes a certain modification, in some respects analogous to polarization, by which it is enabled to pass, with very little diminution, through the second and subsequent glasses.

(3) In those cases where the source of heat is luminous, such phænomena would receive an obvious explanation on the principle investigated in my former Paper. The simple radiant heat being stopped by the first glass, the second would produce an almost insensible diminution of the light, and therefore also of that species of heat which is transmitted in union with it.

But if the same effect is still observable below the point of luminosity, we must have recourse so some other principle of explanation. That deduced by DE LA ROCHE appears at least plausible; and though it should be considered proved, that in general heat is incapable of being radiated directly

through glass, it perhaps would not necessarily follow, that it might not, under peculiar circumstances, have a power of doing so communicated to it. Though on the other hand it must be confessed that, in the present case, some difficulty would attend such a supposition.

It certainly would not be easy to conceive such a property to be communicated to the heat by the mere act of being conducted through the first glass. Again; a new property of heat is thus introduced which, it must be conceded, is not absolutely and exclusively established.

It appeared to me therefore a point of some interest to examine, in the case of non-luminous heat—in the first place, the accuracy of the fact; and secondly, if verified, whether there might not be circumstances observable in the conditions of the experiment by which it might be accounted for, without the necessity of supposing any peculiar property of heat, or a direct transmission even through the second glass.

(4.) My apparatus in following up this enquiry was similar to that described by M. DE LA ROCHE, and consisted of two tin reflectors. In one focus the bulb of a thermometer coated with Indian ink, and in the other an iron ball two inches diameter, which was heated to redness, and then cooled till it ceased to be visibly red in the dark, at which point it was placed on its stand, and a thick screen withdrawn. The indications were observed, first for the direct effect; secondly, with one glass screen interposed; and thirdly, with two. In this way I tried various experiments; in some using only one reflector; in others both; in some employing a mercurial, in others an air thermometer. I conceive it unnecessary to bring forward all the various experiments I tried, and

shall content myself with giving a few of the most decisive, in a tabular form.

The first experiments I shall give, are two sets made with only one reflector, in the focus of which the bulb of a large differential thermometer was placed, and the progress of the effect traced for every 30 seconds successively in the three cases. The area of heating rays was limited by a circular aperture, about two inches diameter, in a pasteboard screen. The first screen, or that nearest the ball, was about $\frac{1}{12}$ inch in thickness, the second rather less. The divisions on the scale are arbitrary.

(5.)

One Reflector. Dist. 18 inches. No. I.				
Min.	Sec.	No Screen.	1 Screen.	2 Screens.
0	—	0	0	0
	30	5	0.5	0
1	—	9	1	0.25
	30	12	1.25	0.25
2	—	13.5	1.25	0.25
	30	14.5	1.5	0.25
3	—	15	1.5	0.25
	30	15.5	1.75	0.5
4	—	15.75	1.75	0.25
	30	16	1.75	0.5
5	—	15.75	1.75	0.5
	30	15.5	1.75	0.5
6	—	15	1.75	0.25
	30	14.25	1.5	0.5
*	*		*	*
8	30		1.5	*
9	—		1.25	*
11	—			0.25

One Reflector. Dist. 18 inches. No. II.				
Min.	Sec.	No Screen.	1 Screen.	2 Screens.
0	—	0	0	0
	30	5	1	0.5
1	—	9.5	1.5	1
	30	13	2	1
2	—	15	2	1
	30	16	2.25	1
3	—	16	2.5	1
	30	16.75	2.5	1
4	—	16	2.25	1.25
	30	15.75	2.25	1.25
5	—	15.5	2	1.25
	30	15	2	1.5
6	—	14.75	2	1.5
*	*			*
8	30			1.5
9	—			1.25
11	—			1.25
	30			1

(6.) In these experiments it appears that the effect with two screens is in a much greater ratio to that with one, than this to the direct effect. It is also obvious on inspection, that the

progress of the direct effect follows a different law from that with one screen, and this again from that with two; and in particular, that the maximum in the last case does not occur till considerably later than in the former. But if the effects were produced by a direct transmission, though their intensity would be diminished, they would follow a similar law; and the maximum would take place at the same time. These results then tend to show that the effect takes place by a secondary radiation. But from the inaccurate nature of the instrument, I place no reliance on these results alone.

(7.) To examine the point in a more complete and satisfactory manner, the two following sets of experiments were made with particular care, in which a mercurial thermometer was used, and the temperatures of the screens observed by means of a small thermometer attached to the face of each away from the ball, towards its central part: the bulb being kept in contact by the spring of a wire with which the thermometer was fastened. These thermometers were very nearly equal in size; the diameters of their bulbs being about 0.175 inch; that of the focal thermometer 0.55 inch, and detached about an inch from the mounting. It was graduated to quarters of centigrade degrees; the others only to whole degrees. Both the screens were of plate glass: the first or nearest the source of heat about $\frac{1}{12}$ inch in thickness; the second about $\frac{1}{8}$ inch.

(8.)

2 Reflectors, 15 inches distant. No. I.

1st. Screen $3\frac{1}{2}$ inches. 2d. 5 inches from ball.

		No Screen.	1 Screen.		2 Screens.		
Min.	Sec.	Focal Therm.	Focal Therm.	Temp. of Screen.	Focal Therm	Temp. of 1st Screen.	Temp. of 2d Screen.
0	—	16.75	16.75	17.5	16.5	18	17
	30	20	17	20	16.5	20	17
1	—	22.5	17.25	21	16.75	22	18
	30	24.5	17.5	24	17	24	18
2	—	25.75	17.75	26	17	25.5	18.5
	30	27	18.	27	17	28	18.5
3	—	28	18.	28.5	17	29.5	18.5
	30	29	18.25	29	17	30	18.5
4	—	29.25	18.25	30	17	31	18.5
	30	29.5	18.5	31	17	31.5	18.75
5	—	29.75	18.5	31	17	32	18.75
	30	30	18.5	31	17	32	18.75
6	—	30	18.5	31	17	32	19
	30	29.75	18.5	31	17	32	19
7	—	29.5	18.5	31	17	32	19
	30	29.5	18.5	31	17	32	19.5
8	—	29	18.5	31	17	31.5	19.5
	30		18.5	30.5	17	31	19.5
9	—		18.5	30	17	31	19.5
	30		18.25	30	17	31	19.5
10	—		18.25	30	17	30.5	19.5
	30		18.25	29.5	16.75	30	19.5
11	—		18.25	29	16.75	29.75	19.5
	30		18.25	29	16.75	29.5	19.5
12	—		18.25	28.5	16.75	29.	19.25
	30		18.25	28.5	16.75	28.75	19.25
13	—		18.25	28.5	16.75	28.5	19
	30		18	28	16.75	28.25	19
14	—		18	28	16.75	28	19

2 Reflectors, 12 inches distant. No. II.
1st Screen 2 in.—2nd $3\frac{1}{2}$ in. from ball.

		No Screen.	1 Screen.		2 Screens.		
Min.	Sec.	Focal Therm.	Focal Therm.	Temp. of Screen.	Focal Therm.	Temp. of 1st Screen.	Temp. of 2d Screen.
0	—	17	17	18	17	17	17
	30	21	17.25	20.5	17	19.5	17
1	—	24	17.75	25	17.25	25.5	17.5
	30	26	18	27	17.5	30	18
2	—	28	18.5	30	17.5	33	18.5
	30	29.5	18.75	32.5	17.5	35	18.5
3	—	30.5	19	34	17.5	37	19
	30	31	19.25	35	17.5	38	19.5
4	—	31.5	19.5	36	17.75	39.5	20
	30	31.5	19.75	37	17.75	40	20
5		31.5	19.75	37.5	17.75	40.5	20
	30	31.5	19.75	37.5	17.75	40.5	20.5
6	—	31.25	19.75	38	17.75	40.5	20.5
	30	31.25	19.75	38	17.75	40.5	21
7	—	31	19.75	38	17.75	40	21
	30		19.75	37.5	17.75	40	21
8	—		19.75	37.5	17.75	39	21
	30		19.75	37	18	39	21
9	—		19.75	36.5	18	38.5	21
	30		19.75	36	18	38	21
10	—		19.75	35.5	17.75	37.5	21
	30		19.75	35	17.75	37	21
11	—		19.5	35	17.75	37	21
	30		19.5	34.5	17.75	36.5	21
12	—		19.5	34	17.75	36	21
	30		19.5	33.5	17.75	35.5	21
13	—		19.25	33	17.75	35	21
	30		19.25	33	17.75	34.5	21
14	—		19.25	32.5	17.75	34	21
	30				17.75	33.5	21
15	—				17.75	3	21

9.) From these results (with which all the others I obtained closely agree) I conceive it fully appears,—

1st. That the additional diminution occasioned by the second

screen is proportionally much smaller than that occasioned by the first. Thus De La Roche's conclusion is shown to hold good, not only in the case of luminous, but also of non-luminous hot bodies; which is perhaps of consequence, as I believe doubts have been entertained respecting it; and it may be remarked, that here the greater thickness of the second screen would be against such a result.

2dly. If the progress of the indications of the direct effect be followed, it appears that the rise in the first 30 seconds is the greatest, and those in the subsequent periods gradually diminish.

3dly. With one screen, the effect in the first period is equal to, or even less than those in the subsequent ones; and if we follow the temperature of the first screen, it appears to sustain a rapid increase at first, and afterwards continues gradually to rise till sometime after the focal thermometer has become stationary.

The progress of the focal thermometer exactly accords with what must be the heating effect of the screen as a source; viz. rising slowly at first as the screen acquires heat sufficient to supply it, and remaining stationary so long as the still increasing temperature of the screen could balance its loss of heat.

4thly. With two screens, there is no rise till the 2d half minute; when it is not greater than in the next half; after which the thermometer becomes stationary; and this trifling effect exactly accords with what the temperature of the second screen should produce. It does not begin till the second screen has acquired a higher temperature, and it is stationary while the temperature of the screen continues to

increase; and the temperature of the second screen is such as is clearly accounted for from the heating effect of the first. It does not begin to rise till after that of the first has risen: it continues stationary some time after the first has begun to cool, as the first screen did when the iron was cooling. But, as in this case, the source of heat was cooling during the whole time of the experiment, whilst in the other it was heating during the first part of the time, it follows, that a greater proportional temperature should be communicated to the second screen by the first, than to the first by the iron ball.

Other circumstances will partially co-operate in producing this effect; as the greater proximity of the second screen to the thermometer: also more heat might be lost in communicating an equable temperature to the first screen from its central and most heated part; whilst the heat would be thus more equally radiated to all parts of the second without such loss.

Thus it appears that the fact stated by M. DE LA ROCHE is fully substantiated; while on the other hand it is satisfactorily accounted for, without supposing any new property of heat, or any direct radiation through glass.

(10.) I have been more particularly led to this enquiry, from becoming acquainted with some experiments on the subject by Mr. RITCHIE, published in the Edinburgh Philosophical Journal, No. XXII. p. 281; in which, among other conclusions (to which I shall presently advert), he maintains, that at high temperatures below luminosity a portion of the heat radiates through glass of ordinary thickness, but without giving any details by which it can be made to appear that the effect is not sufficiently accounted for by secondary radiation. He has also given an explanation on his own

theory of the conclusion I have above examined, as deduced from De La Roche's experiments; but both that conclusion, and with it any such explanation, are now I conceive shown to be unnecessary.

(11.) The principal result obtained by Mr. Ritchie, and described in this Paper, is however of a nature deserving more attention. It exhibits an *exception* to the general law, in the instance of *glass of extreme thinness;* in which case the heat from a source below luminosity appears capable of radiating through such a screen when *transparent*, but not when rendered *opaque*.

As experiments conducted like those of Mr. Ritchie, with air thermometers, are always liable to uncertainty, I conceived it desirable to try the same thing with a mercurial thermometer.

(12.) I used as screens pieces of a large bulb blown to an extreme degree of tenuity; these were attached (as in Mr. Ritchie's experiments), to a circular aperture about $\frac{3}{4}$ inch diameter in a pasteboard screen. A second screen of milled board, with an aperture of 1 inch diameter, was placed about an inch from the first; and behind this the iron ball, previously cooled to just below visible redness. The same thermometer as in the preceding experiments was suspended at about $\frac{1}{2}$ inch from the screen. I made various trials, comparing the effect of the thin transparent screen with a similar opaque one: in some instances using three thicknesses of the glass, and afterwards the middle piece blackened on both sides with the soot of a candle; and in others two thicknesses, the inner surface of one being afterwards blackened; thus forming an opaque screen with the same vitreous surface. In all the experiments a thermometer suspended by the side

of the apparatus did not vary. The results of two sets of experiments are as follows:

Distance 6 inches. No. I.

Min.	Sec.	3 Glasses.		Middle Glass blackened.		2 Glasses. 2d blackened.
		Exp. 1.	Exp. 2.	Exp. 1.	Exp. 2.	
0	—	17.25	17.25	17.25	17.25	17.25
	30	17.5	17.5	17.5	17.5	17.5
1	—	17.75	17.75	17.5	17.75	17.75
	30	17.75	17.75	17.75	17.75	17.75
2	—	18	17.75	17.75	17.75	18
	30	18	18	17.75	17.75	18
3	—	18	18	18	18	18

Distance 3 inches. No. II.

Min.	Sec.	1 Glass.	2 Glasses.	2 Glasses. 2d blackened.	
				Exp. 1.	Exp. 2.
0	—	15.25	15.5	16	16
	30	16	16.25	16.5	16.75
1	—	16.5	16.5	16.75	17
	30	17	17	17.25	17.25
2	—	17.25	17.25	17.75	17.75

(13.) From these results, I think it will be admitted that no sensible difference appears in the two cases, sufficient to warrant any such conclusion as that alluded to. If the experiments described in this paper be regarded as sufficiently accurate, it follows upon the whole, that two principal exceptions to the general law, that simple heat cannot radiate through glass, are done away.

St. Helen's Place, March 9, 1826.